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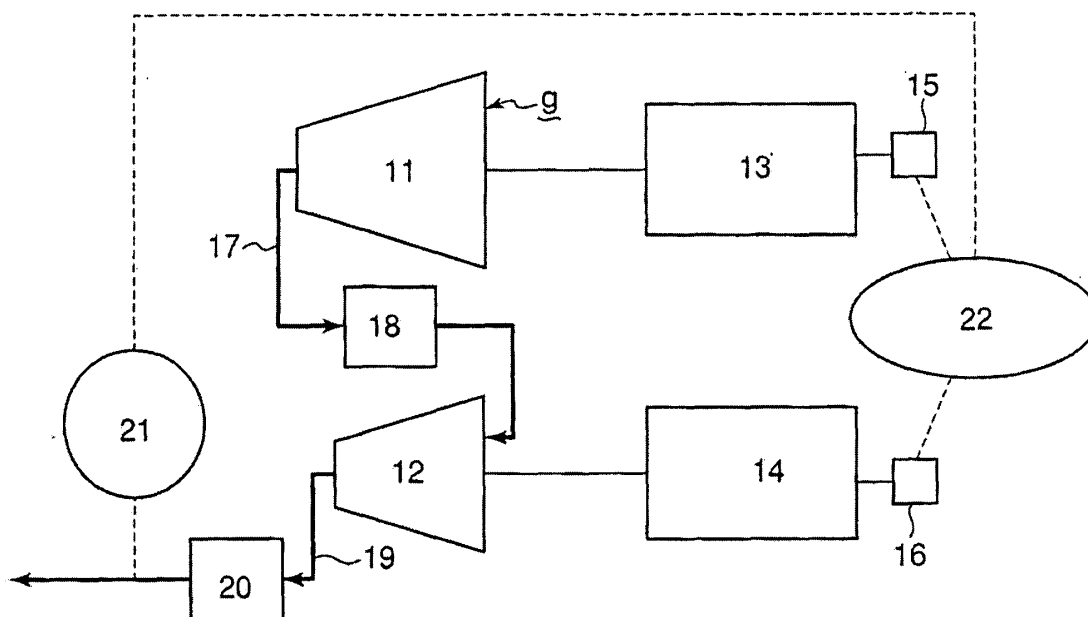
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(54) **Rotary compressor unit and method of controlling operation thereof**

(57) The compressor unit having at least two compressors, for example a low pressure stage compressor (11) and a high pressure stage compressor (12) connected in series, of which the low pressure stage compressor (11) and high pressure stage compressor (12) are driven by driving devices (13 and 14) respectively separately or driven by a single driving device (41) via variable speed

gears (43 and 44) respectively connected to each of the compressors, and rotation speed of the low pressure stage compressor (11) and that of the high pressure stage compressor (12) are controlled independently in accordance with various operating conditions of the compressor unit so that optimal load balancing of the compressors (11 and 12) is always achieved.

FIG. 1



Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a rotary compressor unit composed of a lower pressure stage compressor and a higher pressure stage compressor connected in series, and a method of controlling operation thereof, the unit being made possible to be operated with proper load balance of each of the compressors, thereby achieving efficient operation of the unit.

Description of the Related Art

[0002] Generally, a tooth type rotary compressor consists of two rotors, a male rotor and a female rotor, each having claw-like teeth, or lobes. They turn in opposite directions without contact to each other to compress gas trapped in the compression pockets formed between the lobes and inner surface of a compressor casing as the rotors rotate. As the rotors do not contact with each other and with the inner surface of the compressor casing, the rotors do not wear and have a long life. Further, lubrication of the rotors is not needed because of non-contact engagement of the rotors, and clean compressed gas not contaminated with lubricant can be obtained. Compression ratio obtained by this type of compressor is relatively low, and required high compression ratio is obtained with high efficiency in many cases by composing a two-stage compressor unit comprised of a lower pressure stage compressor and a higher pressure stage compressor connected in series. Working of the tooth type compressor will be explained hereunder referring to FIG. 4a to FIG.4d

[0003] In FIG.4a, a male rotor 02 having claw-like lobes engages with a female rotor 03 having claw-like lobes with very tight clearances in a compressor housing 01. Gas g to be compressed is sucked from a suction opening 04 as the rotors 02 and 03 rotate in directions indicated by arrows. In FIG. 4b, the suction opening 04 is closed by the rotors 02, 03, and the sucked gas g is confined in a pocket surrounding the lobes of the female rotor 03 and in a pocket surrounding the lobes of the male rotor 02. In FIG.4c, the two pockets are communicated and the volume of the sum of the two pockets is reduced as the rotors rotate to compress the gas. In FIG.4d, compressed gas c is discharged through outlet openings 05 provided in both sides of the compressor housing 01 and opened by the side faces of the female rotor 03 as the rotors rotate.

[0004] Conventionally, a single electric motor has been used to drive two compressors, a low pressure stage compressor and a high pressure stage compressor of a two-stage compressor unit as shown in FIG.5 for space shaving and plant cost reduction. In FIG.5, a drive gear 08 attached to an output shaft 07a of an electric

motor 07 meshes with a gear 09a attached to a rotor shaft 06a of a male rotor 02a of a low pressure stage compressor and a gear 09b attached to a rotor shaft 06b of a male rotor 02b of a high pressure stage compressor.

5 [0005] The male rotor 02a of the low pressure stage compressor and the male rotor 02b of the high pressure stage compressor are driven together by the single electric motor 07. The male rotor and female rotor of each compressor are synchronized via a timing gear 010a and 020b respectively.

10 [0006] A rotary compressor unit having two compressors driven by a single electric motor is disclosed in Japanese Laid-Open Patent Application No.1-193089 (patent literature 1) and in Japanese Laid-Open Patent Application No.4-6349 (patent literature 2).

15 [0007] In designing a rotary compressor unit composed of a low pressure stage compressor and a high pressure stage compressor, usually the displacement volume of each of the compressor is determined so that the driving power of each of the compressors is nearly equal when the unit is operated at its rated discharge pressure of the unit. The displacement volume each of the compressors can not be changed in operation of the unit. Rotation speed of the low pressure stage compressor and that of the high pressure stage compressor are determined by the rotation speed of the electric motor 07 and the ratio of number of teeth of the gear 09a to the gear 08 and that of the gear 09b to the gear 08. Usually, these ratios are determined to be equal so that both the compressors are rotated at the same rotation speed.

20 [0008] Rotation speed of the electric motor can be varied by inverter control in accordance with various operating conditions. For example, in Japanese Laid-Open Patent Application No.2002-39079 (patent literature 3) is disclosed a method of using a plurality of electric motors to drive the orbiting scroll of a scroll compressor, in which the motors are controlled by inverters. In Japanese Laid-Open Patent Application No.2004-360464 (patent literature 4) is disclosed an oil-free screw compressor whose rotation speed is controlled by an inverter.

25 [0009] As mentioned above, with a compressor unit having a low pressure stage compressor and a high pressure stage compressor and driven by a single electric motor as shown in FIG. 5, rotation speed of each compressor can not be controlled separately. Operation of such a compressor unit will be explained referring to FIG. 6 showing a P-V diagram thereof (P represents pressure and V specific volume of the gas). In FIG. 6, gas is first compressed by the low pressure stage compressor to 0.2 MPa, then the compressed gas is cooled through an intermediate cooler to be reduced in specific volume as shown by an arrow x. Then the compressed and cooled gas is further compressed to 0.7 MPa by the high pressure stage compressor, for example.

30 [0010] However, the compressor unit is not always operated to produce the rated discharge pressure of the unit. A compressor unit of rated discharge pressure of 0.7 MPa may be operated to produce discharge pressure

of 0.5 MPa as shown by a lateral line y or to produce discharge pressure of 0.8 MPa transiently as shown by a lateral line z in FIG. 6. By the inverter control mentioned above, rotation speed of the electric motor is controlled by the inverter, and rotation speed of the low pressure stage compressor and that of the high pressure stage compressor can no be controlled separately.

[0011] In a case the compressor unit is operated to produce a discharge pressure lower than the rated discharge pressure of the unit as shown by the lateral line y, a large part of compression work is done by the low pressure compressor and the high pressure stage compressor achieves a little part of the compression work of the compressor unit. Therefore, unbalance in load occurs between the low pressure stage compressor and the high pressure stage compressor, and temperature rise in the low pressure stage compressor becomes larger than that in the high pressure stage compressor, compression efficiency of the low pressure stage compressor decreases leading to decreased compression efficiency of the compressor unit, and in addition deleterious effect is caused on the durability of the compressor unit.

To achieve proper load balancing of the low pressure stage and high pressure stage compressors, it is needed to decrease the rotation speed of the low pressure stage compressor and increase the rotation speed of the high pressure stage compressor, which is however not possible with the conventional drive system of the compressor unit.

[0012] In a case the compressor unit is operated to produce a discharge pressure higher than the rated discharge pressure of the unit as shown by the lateral line z, the load of the high pressure stage compressor becomes relatively larger as compared to the load of the low pressure stage compressor and unbalance in load occurs in the two compressors. Therefore, temperature rise in the high pressure stage compressor becomes larger than that in the low pressure stage compressor causing decrease in compression efficiency of the high pressure stage compressor. Consequently, compression efficiency of the compressor unit is decreased and in addition deleterious effect is caused on the durability of the compressor unit. To achieve load balancing of the low pressure stage and high pressure stage compressors, it is needed to increase the rotation speed of the low pressure stage compressor and decrease the rotation speed of the high pressure stage compressor, which is however not possible with the conventional drive system of the compressor unit.

SUMMARY OF THE INVENTION

[0013] The present invention was made in light of problems of prior arts, and the object of the invention is to make it possible to operate a rotary compressor unit comprised of at least two compressors connected in series and driven separately with optimal compression efficiency always irrelevant to discharge pressure of the com-

pressor unit by making it possible to control rotation speed of each of the compressors independently.

[0014] To attain the object, the present invention proposes a method of controlling operation of a rotary compressor unit comprised of a low pressure stage compressor and a high pressure stage compressor connected in series, wherein

said low stage and high stage compressors are driven by driving devices each for driving each compressor or by a single driving device via variable speed gears each connected to each compressor and driven by said single driving device, and

rotation speed of each of said compressors is controlled independently in accordance with various operating conditions of the compressor unit so that loads of the compressors are balanced.

[0015] According to the operating method of the invention, each rotation speed of the compressors can be controlled independently through driving each compressor of each stage by a separate driving device respectively or by a single driving device via a separate variable speed gear respectively. Therefore, optimum load-balancing of the compressors can be achieved so that each compressor of the compressor unit is operated at nearly the same load at all operating conditions of the compressor unit. As a result, the compressor unit can be operated always with optimal efficiency, and in addition durability of the compressor unit can be improved.

[0016] For example, when the compressor unit is operated to produce a discharge pressure lower than the rated discharge pressure of the unit, the rotation of the low pressure stage compressor is controlled to be larger than that of the high pressure stage compressor, thereby achieving optimal load balancing of the low pressure stage and high pressure stage compressors so that temperature rise in each compressor is nearly equal, and when the compressor unit is operated to produce a discharge pressure higher than the rated discharge pressure of the unit, the rotation of the high pressure stage compressor is controlled to be larger than that of the low pressure stage compressor, thereby achieving optimal load balancing of both the compressors so that temperature rise in each compressor is nearly equal.

[0017] It is preferable in the invention that discharge side gas pressure of the high pressure stage compressor is detected or discharge side gas pressure of the high pressure stage compressor and discharge side gas pressure of the low pressure stage compressor are detected, and rotation speed of each of the compressors is controlled independently based on the detected pressure value or values.

[0018] To practice the operating method of the invention, a rotary compressor unit comprised of a low pressure stage compressor and a high pressure stage compressor connected in series is proposed as a first invention of the compressor unit, wherein

each of said low stage compressor and high stage compressor has a driving device for driving each of the com-

pressors respectively and each driving device is provided with an inverter circuit for varying frequency of power supply to said each driving device, and a controller is provided to control rotation speed of said each driving device via said each inverter circuit in accordance with various operating conditions of the compressor unit so that loads of said compressors are balanced.

[0019] As the compressor unit of the first invention composed such that each of the compressors is driven by an electric motor which is provided with an inverter circuit and connected to each compressor respectively, rotation speed of each of the compressors can be controlled independently by the controller through controlling frequency of power supply to each compressor via each inverter circuit.

[0020] The invention also proposes as second invention of the compressor unit a rotary compressor unit comprised of a low pressure stage compressor and a high pressure stage compressor connected in series, comprising:

a single driving device for driving said low pressure stage and high stage compressors,
a variable speed gear connected to said low pressure stage compressor and driven by said single driving device,
another variable speed gear connected to said high pressure stage compressor and driven by said single driving device, and
a controller for controlling rotation speed of each of said compressors independently via each of said variable speed gears in accordance with variable operating conditions of the compressor unit so that loads of the compressors are balanced.

[0021] The compressor unit of the second invention is provided with only a single electric motor, and rotation speed of each of the compressors is controlled independently by the controller through controlling each of the variable speed gears driven by the single electric motor.

[0022] According to the compressor unit of the first and second invention, rotation speed of each of the compressors composing the compressor unit can be controlled so that load balancing of the compressors is achieved, so the compressor unit can be operated always with optimal compression efficiency, and in addition durability of the compressor unit can be improved.

[0023] It is preferable in the compressor unit of the first and second invention that a pressure sensor for detecting discharge side gas pressure of the high pressure stage compressor is provided or a pressure sensor for detecting discharge side gas pressure of the low pressure stage compressor is further provided in addition to said pressure sensor for detecting discharge side gas pressure of the high pressure stage compressor, and rotation speed of each of the compressors is controlled independently based on the pressure detected by the pressure sensor

or sensors.

[0024] According to the invention, rotation speed of each compressor of the compressor unit comprised of a low pressure stage compressor and a high pressure stage compressor connected in series and driven separately can be controlled independently, optimal load balancing of the compressors can be achieved for various operating conditions of the compressor unit, as a result the compressor unit can be operated with optimal efficiency always in accordance with various operating conditions of the compressor unit, in addition durability of the compressor unit can be improved.

[0025] The invention can be applied to a compressor unit further having one or more of intermediate pressure stage compressors connected in series to the low and high pressure stage compressors, and load balancing of the compressors can be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026]

FIG. 1 is a schematic overall configuration of the first embodiment of the invention.

FIG. 2 is a schematic overall configuration of the second embodiment of the invention.

FIG. 3 is a schematic overall configuration of the third embodiment of the invention.

FIG. 4a to 4d are drawings for explaining working of a tooth type rotary compressor.

FIG. 5 is a schematic configuration of drive mechanism of a conventional compressor unit having a low pressure stage compressor and a high pressure stage compressor.

FIG. 6 is a P-V diagram of a conventional compressor unit having a low pressure stage compressor and a high pressure stage compressor.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0027] Preferred embodiments of the present invention will now be detailed with reference to the accompanying drawings. It is intended, however, that unless particularly specified, dimensions, materials, relative positions and so forth of the constituent parts in the embodiments shall be interpreted as illustrative only not as limitative of the scope of the present invention.

(The first embodiment)

[0028] A first embodiment of the invention will be explained referring to FIG. 1. FIG. 1 is a schematic overall configuration of a rotary compressor unit having a low pressure stage compressor and a high pressure compressor of tooth type for example. Referring to FIG. 1, the rotary compressor unit comprises a low pressure stage compressor (hereafter referred to as LP compressor) 11,

a high pressure stage compressor (hereafter referred to as HP compressor) 12, a LP compressor driving electric motor (hereafter referred to as LP motor) 13 connected directly to the LP compressor 11, and a HP compressor driving electric motor (hereafter referred to as HP motor) 14 connected directly to the HP compressor 12. Further, a LP motor controlling inverter circuit (hereafter referred to as LP inverter circuit) 15 for varying rotation speed of the LP motor 13 by varying frequency of power supply to LP motor 13 and a HP motor controlling inverter circuit (hereafter referred to as HP inverter circuit) 16 for varying rotation speed of the HP motor 14 by varying frequency of power supply to the HP motor 14 are provided.

[0029] Gas g to be compressed sucked into the LP compressor 11 is compressed for example to 0.2 MPa by the LP compressor 11. The compressed gas discharged from the LP compressor 11 is cooled through an intercooler 18 provided in a discharge flow path 17 and then sucked into the HP compressor 12 to be further compressed for example to 0.7 MPa.

[0030] The gas compressed through the HP compressor 12 and discharged therefrom is cooled through an aftercooler 20 provided in a discharge flow path 19 and then supplied to user equipment. A pressure sensor 21 is provided at the downstream side of the aftercooler 20 to detect the discharge pressure of the HP compressor 12. Further, a controller 22 is provided to control the LP inverter circuit 15 and HP inverter circuit 16 based on the discharge pressure detected by the pressure sensor 21.

[0031] Discharge gas pressure of the HP compressor 12 detected by the pressure sensor 21 attached to the discharge flow path 19 is inputted to the controller 22. The controller 22 controls the LP inverter circuit 15 and HP inverter circuit 16 so that optimal load balancing of the LP compressor 11 and HP compressor 12 is achieved by controlling the rotation speed of each compressor independently.

[0032] When operating the compressor unit to produce a discharge pressure lower than the rated pressure, for example, when operating a compressor unit of rated discharge pressure of 0.7 MPa to produce discharge pressure of 0.5 MPa as indicated by the lateral line y in FIG. 6, the controller 22 controls so that the rotation speed of the LP compressor 11 is larger than that of the HP compressor 12 to achieve load balancing of the compressors 11 and 12 so that temperature rise caused by compression in each compressor is nearly equal.

There may be a case the compressor unit is operated to produce a discharge pressure of 0.8 MPa as shown by the lateral line z in FIG. 6. In such a case, the controller 22 controls so that the rotation speed of the HP compressor 12 is larger than that of the LP compressor 11 to achieve load balancing of the compressors 11 and 12 so that temperature rise caused by compression in each compressor is nearly equal.

[0033] By controlling rotation speed of the LP compressor 11 and that of the HP compressor 12 independently in this way, load balancing of the LP compressor 11 and

HP compressor 12 is always achieved even when the compressor unit is operated to produce a discharge pressure different from the rated discharge pressure of the unit. Therefore the compressor unit can be operated always with optimal compression efficiency irrelevant to required discharge pressure of the compressor unit, as a result, efficient operation of the compressor unit can be always achieved, and in addition, endurance of the compressor unit can be improved.

[0034] As the discharge pressure of the HP compressor 12 is detected by the pressure sensor 21 and rotation speed of the LP and HP compressors 11, 12 are controlled independently via the LP and HP inverter circuits 15, 16, load balancing of the LP compressor 11 and HP compressor 12 can be achieved with a high degree of accuracy in accordance with various discharge pressures of the HP compressor 12.

(The second embodiment)

[0035] Next, a second embodiment of the invention will be explained referring to FIG.2. In FIG.2, constituents same as those of FIG.1 are denoted by the same reference numerals and explanation of them is omitted. Different point of the second embodiment of FIG.2 from the first embodiment of FIG.1 is that an intermediate pressure sensor 31 is provided to the discharge flow path 17 to detect discharge pressure of the LP compressor 11. Otherwise is the same as the first embodiment of FIG.1. The pressure value detected by the intermediate pressure sensor 31 is inputted to the controller 22 in addition to the pressure value detected by the pressure sensor 21, and rotation speed of the LP and HP compressors 11, 12 are controlled via the LP and HP inverter circuits 15, 16 base on both the detected pressure values.

[0036] With this configuration of the second embodiment, not only the discharge pressure of the HP compressor 12 is detected in the discharge flow path 19 but also the discharge pressure of the LP compressor 11 is detected in the discharge flow path 17, and optimal load balancing of the LP compressor 11 and HP compressor 12 can be achieved based on both the discharge pressure of the LP compressor and HP compressor. Therefore, further efficient operation of the compressor unit can be achieved.

(The third embodiment)

[0037] Next, a third embodiment of the invention will be explained referring to FIG.3. In FIG.3, constituents the same as those of FIG.2 are denoted by the same reference numerals and explanation of them is omitted. Difference of the third embodiment of FIG. 3 from the second embodiment of FIG. 2 is that a single electric motor 41 is employed to drive the compressor unit, a variable speed gear (hereafter referred to as LP transmission) 43 is provided for varying the rotation speed of the LP compressor 11, a variable speed gear (hereafter

referred to as HP transmission) 44 is provided for varying the rotation speed of the HP compressor 12, and a gear box 42 is connected to the electric motor 41, whereby the LP compressor 11 and HP compressor 12 are driven via the LP transmission 43 and HP transmission 44 respectively. Otherwise is the same as the second embodiment of FIG.2.

[0038] With the compressor unit of the third embodiment, rotation of the electric motor 41 is transmitted to the LP and HP compressors 11, 12 via the gear box 42 and via the LP and HP transmissions 43, 44 respectively. The LP transmission 43 and HP transmission 44 are controlled by the controller 22. Therefore, rotation speed of the LP compressor 11 and HP compressor 12 can be controlled independently.

[0039] As the rotation speed of the LP compressor and that of the HP compressor can be controlled independently, the compressor unit can be controlled so that optimal load-balancing of the LP compressor 11 and HP compressor 12 is always achieved when the compressor unit is operated to produce a discharge pressure different from the rated discharge pressure of the unit. Therefore, the compressor unit is always operated efficiently, and in addition, endurance of the compressor unit can be improved.

[0040] By detecting the discharge pressure of the HP compressor 12 and LP compressors 11 by the pressure sensor 21 and intermediate pressure sensor 31 and controlling the rotation speed of the HP compressor 12 and LP compressor 11 based on the detected pressures, optimal load-balancing of the LP compressor 11 and HP compressor 12 can be maintained with a high degree of accuracy in accordance with various discharge pressures. Further, as the compressor unit is driven by the single electric motor 41, installation space plant cost can be saved.

[0041] Although a case of the compressor unit comprised of two compressors, the low stage and high stage compressors connected in series is explained in the foregoing, it can be easily understood that similar effect can be obtained when one or more intermediate pressure stage compressors driven separately are connected in series with the low stage and high stage compressors.

INDUSTRIAL APPLICABILITY

[0042] According to the invention, compressor unit comprised of a plurality of compressors connected in series can be controlled such that rotation speed of each of the compressors is varied independently, optimal load-balancing of the compressors is achieved, as a result operation of the compressor unit can be performed efficiently.

Claims

1. A method of controlling operation of a rotary com-

pressor unit comprised of a low pressure stage compressor and a high pressure stage compressor connected in series, wherein

said low pressure stage and high pressure stage compressors are driven by driving devices each for driving each compressor or by a single driving device via variable speed gears each connected to each compressor and driven by said single driving device, and rotation speed of each of said compressors is controlled independently in accordance with various operating conditions of the compressor unit so that loads of said compressors are balanced.

2. A method of controlling operation of a rotary compressor unit according to claim 1, wherein discharge side gas pressure of the high pressure stage compressor is detected or discharge side gas pressure of the high pressure stage compressor and discharge side gas pressure of the low pressure stage compressor are detected, and rotation speed of each of the compressors is controlled independently based on the detected pressure value or values.

3. A rotary compressor unit comprised of a low pressure stage compressor and a high pressure stage compressor connected in series, wherein

each of said low pressure stage compressor and high pressure stage compressor has a driving device for driving each of the compressors respectively and each driving device is provided with an inverter circuit for varying frequency of power supply to said each driving device, and a controller is provided to control rotation speed of said each driving device via said each inverter circuit in accordance with various operating conditions of the compressor unit so that loads of said compressors are balanced.

4. A rotary compressor unit comprised of a low pressure stage compressor and a high pressure stage compressor connected in series, comprising:

a single driving device for driving said low pressure stage and high pressure stage compressors,

a variable speed gear connected to said low pressure stage compressor and driven by said single driving device,

another variable speed gear connected to said high pressure stage compressor and driven by said single driving device, and

a controller for controlling rotation speed of each of said compressors independently via each of said variable speed gears in accordance with

various operating conditions of the compressor unit so that loads of said compressors are balanced.

5. A rotary compressor unit according to claim 3 or 4, wherein a pressure sensor for detecting discharge side gas pressure of the high pressure stage compressor is provided or a pressure sensor for detecting discharge side gas pressure of a low pressure stage compressor is further provided in addition to said pressure sensor for detecting discharge side gas pressure of the high pressure stage compressor, and rotation speed of each of the compressors is controlled independently based on the pressure detected by the pressure sensor or sensors.
6. A method of controlling operation of a rotary compressor unit according to claim 1 or 2 further comprising one or more of intermediate pressure stage compressor or compressors connected in series with said low and high pressure stage compressors, the intermediate pressure stage compressor or compressors being driven separately by a separate driving device or devices or by said single driving device via a separate variable gear or gears and controlled in rotation speed independently so that load balancing of all of the compressors is achieved.
7. A rotary compressor unit according to any one of claims 3-5 further comprising one or more of intermediate pressure stage compressor or compressors connected in series with said low and high pressure stage compressors, the intermediate pressure stage compressor or compressors being driven separately by a separate driving device or devices or by said single driving device via a separate variable gear or gears and controlled in rotation speed independently so that load balancing of all of the compressors is achieved.

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FIG. 1

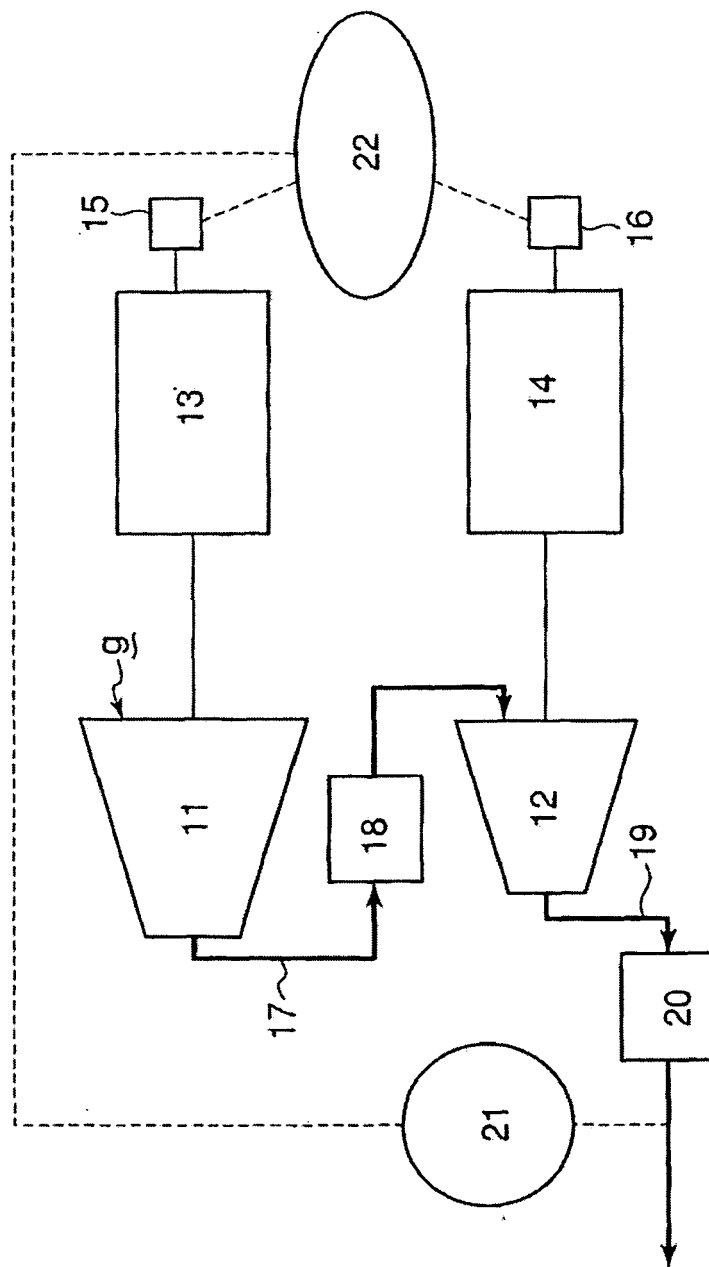


FIG. 2

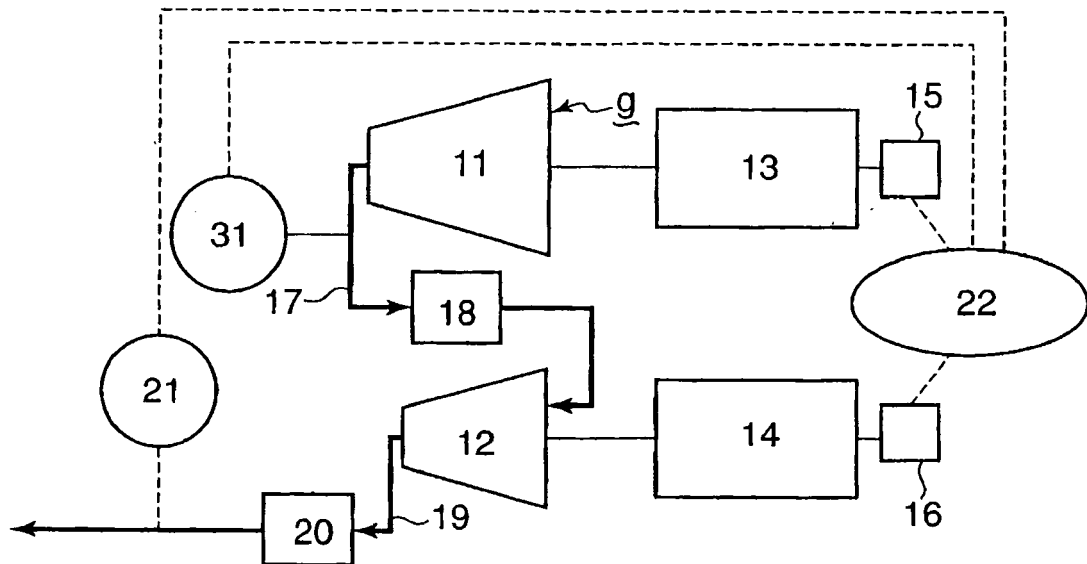


FIG. 3

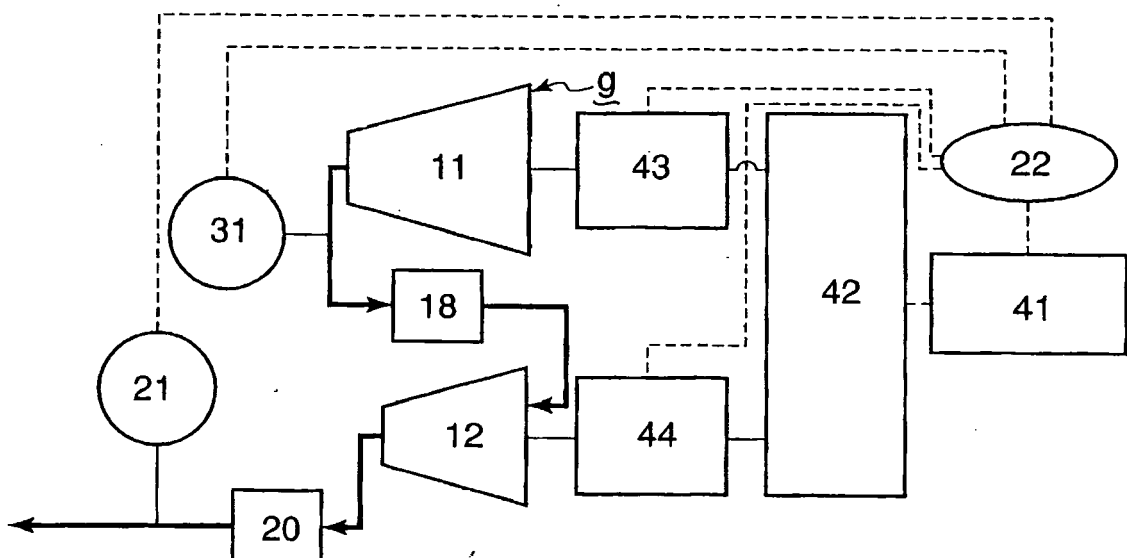


FIG. 4

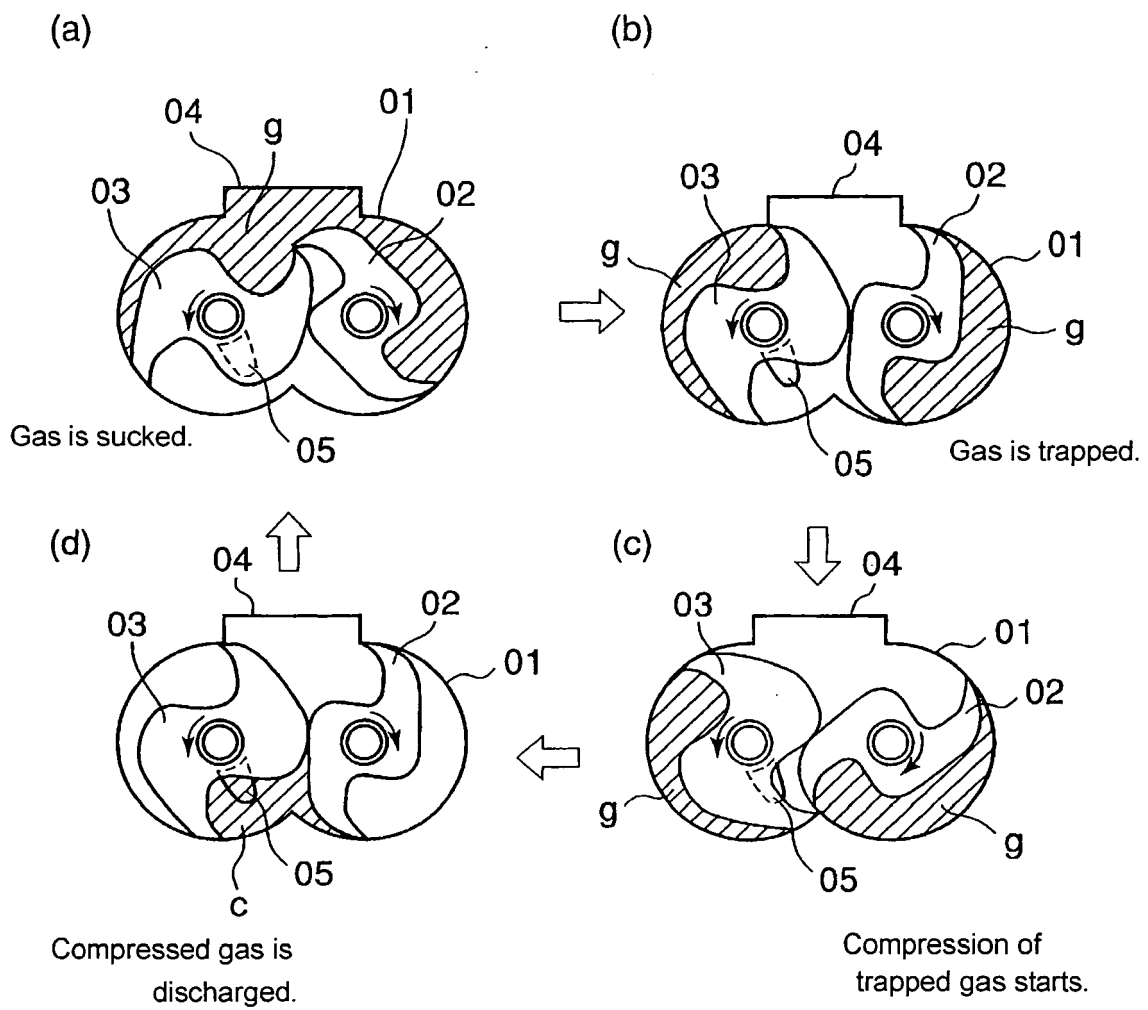


FIG. 5

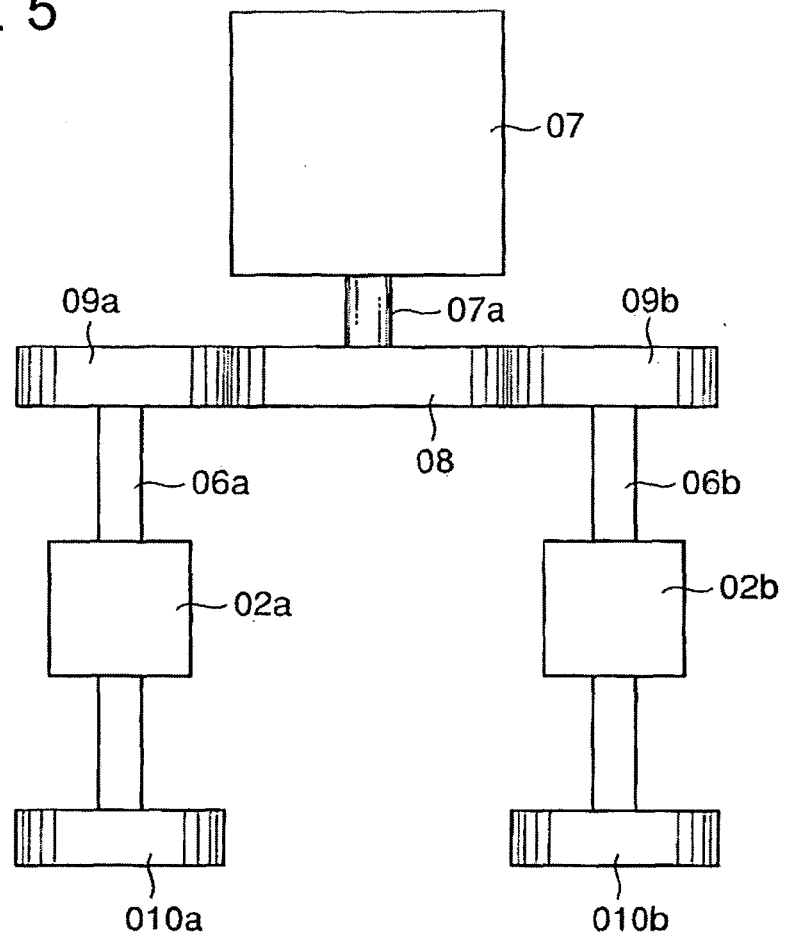
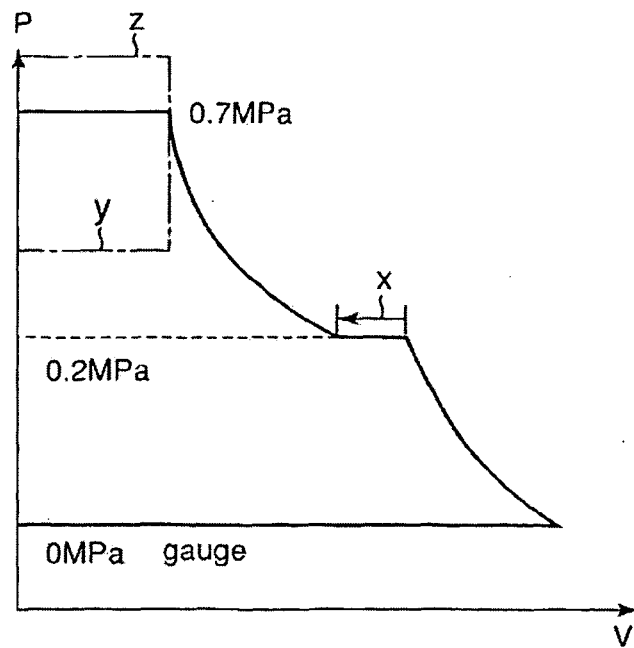


FIG. 6



REFERENCES CITED IN THE DESCRIPTION

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